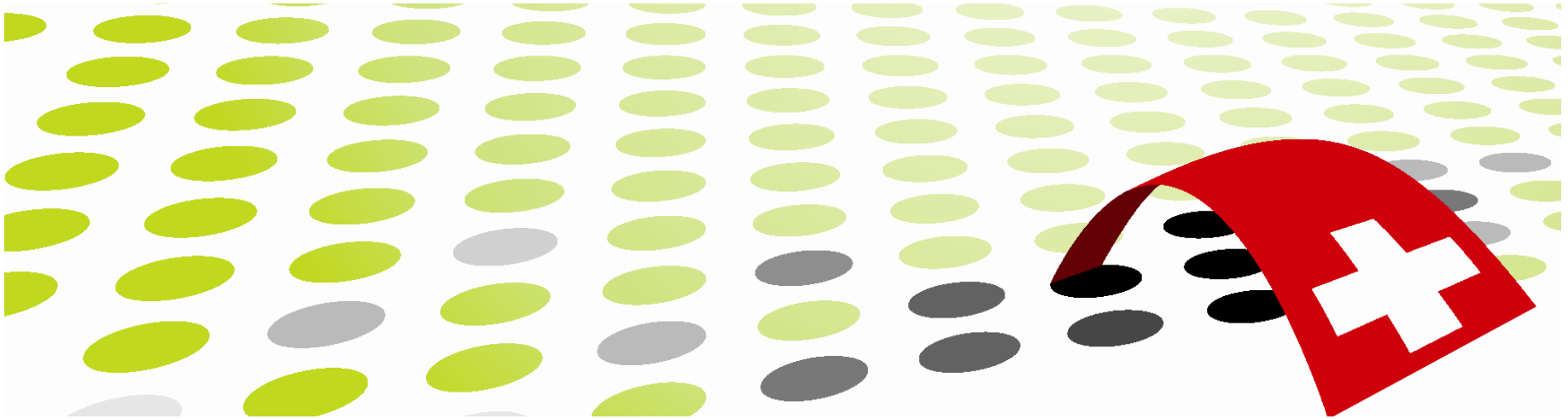
Nano-Tera.ch

Engineering Complex Systems

for Health, Security and the Environment

Giovanni De Micheli

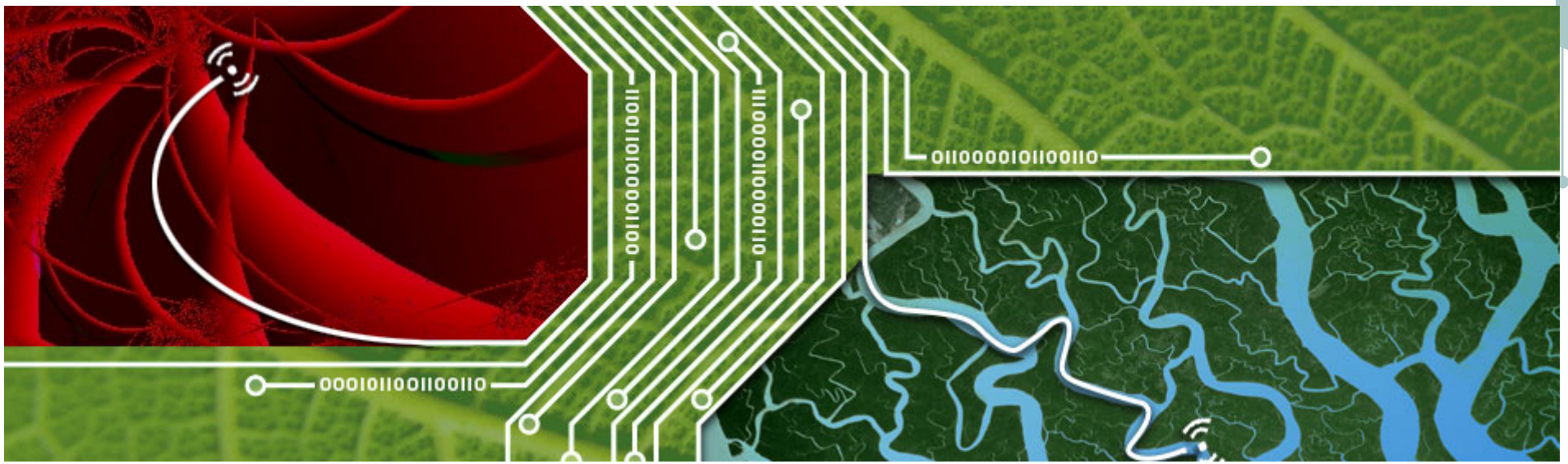


Emerging societal and economic issues

The technology

Nano-Tera.ch

- Health:
  - High-throughput biology, real-time medical monitoring
- Environmental monitoring:
  - Weather, pollution, seismic analysis
- Security:
  - Cryptography, secure communication



Mission

Research, Design & Engineering of complex tera-scale systems using nano-scale devices and technologies

Foster research and crossbreeding of hw/sw technologies

Convergence of technologies: fertile ground for innovation

- **Develop new markets**
- **Improve living standards**
- **Better the quality of health, security & environment systems**
- **Foster a vision of engineering with social objectives**
- **Promote related educationl programs**

nano-tera.ch

Nano-Tera.ch: key figures

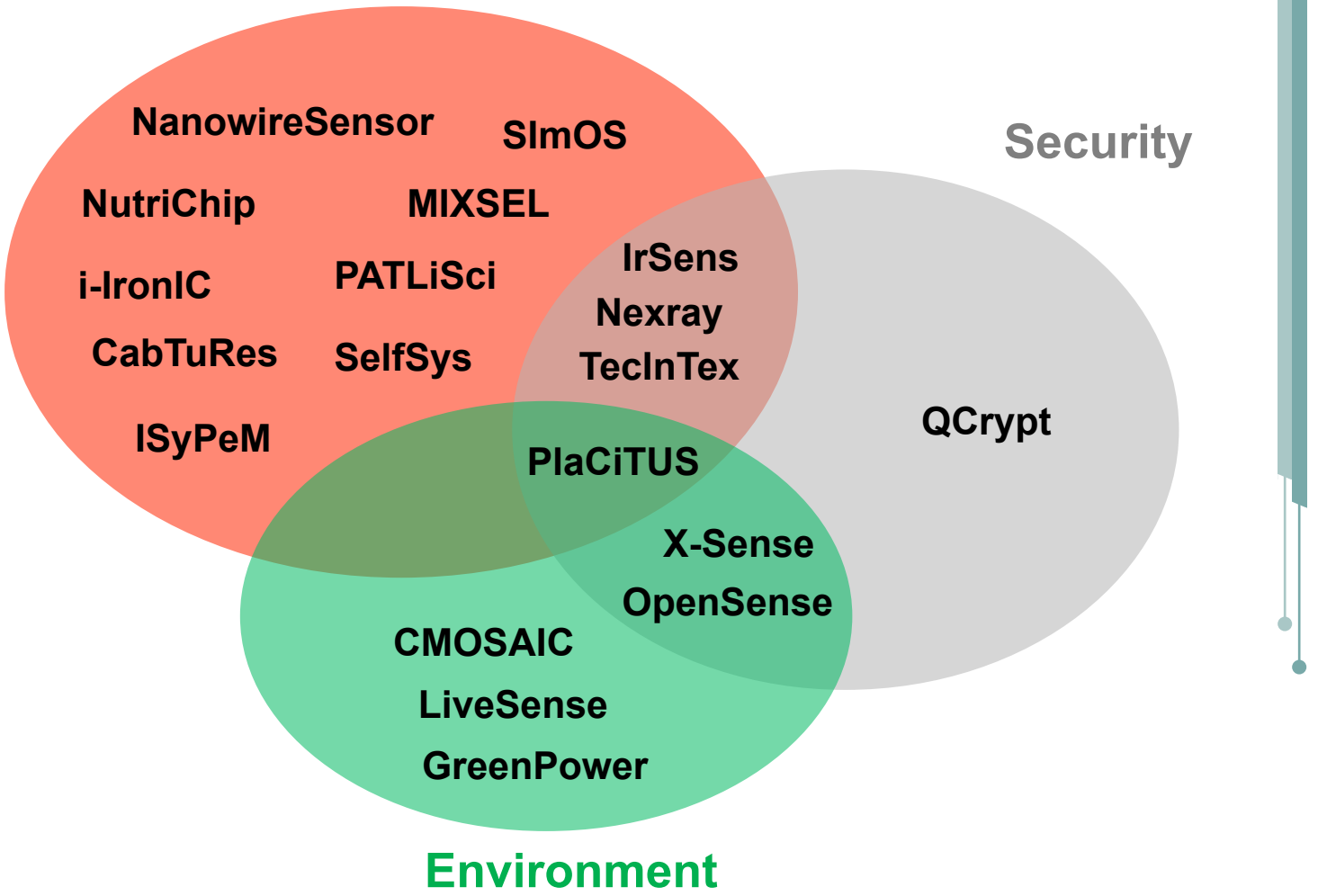
- **59** Projects (19 RTD – 15 NTF – 19 ED – 6 SSSTC)
- **37** Research institutions (involved with PIs or CoPIs)
- **150** Research groups
- **27** Industrial partners
- **~700** Researchers
- **~120** Doctoral theses supported
- **> 300** Papers published (2010-2011)
- Total Nano-Tera.ch funding support (2008-2011):
  - **60 M CHF** in cash (from Swiss Confederation)
  - **61.8 M CHF** in matching money
- Total funding support for 2012:
  - **15 M CHF** in cash **15 M CHF** in matching support
- Support for 2013-2016 is being negotiated

RTD projects

- Research, Technology and Development projects
  - Multi-discipline projects
  - Multi-institution projects
- Research on fundamental principles
- Applications toward technology demonstrators
- Selected and monitored through the Swiss National Science Foundation
- Budgets around 1MCHF/year (in cash)
- 19 projects currently supported

RTD Projects by themes

19 RTD projects
3-4 years



Consortium institutions

Leading House

EPFL Swiss Federal Institute of Technology Lausanne

Consortium

CSEM Swiss Center for Electronics and Microtechnology

EPFL Swiss Federal Institute of Technology Lausanne

ETHZ Swiss Federal Institute of Technology Zurich

UniBas University of Basel

UniGE University of Geneva

UniNE University of Neuchâtel

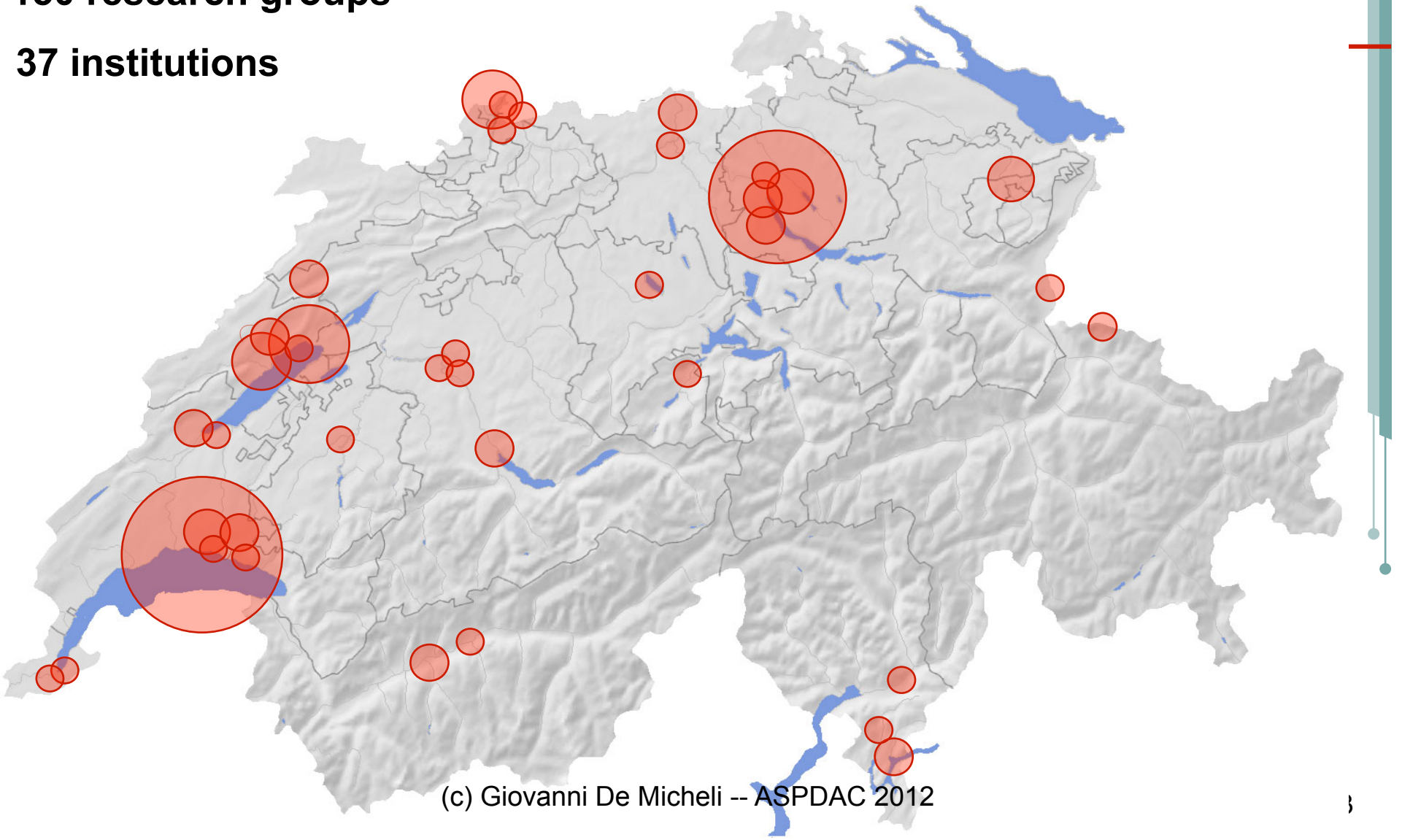
USI University of Lugano

37 participating institutions

Distribution of research groups

150 research groups

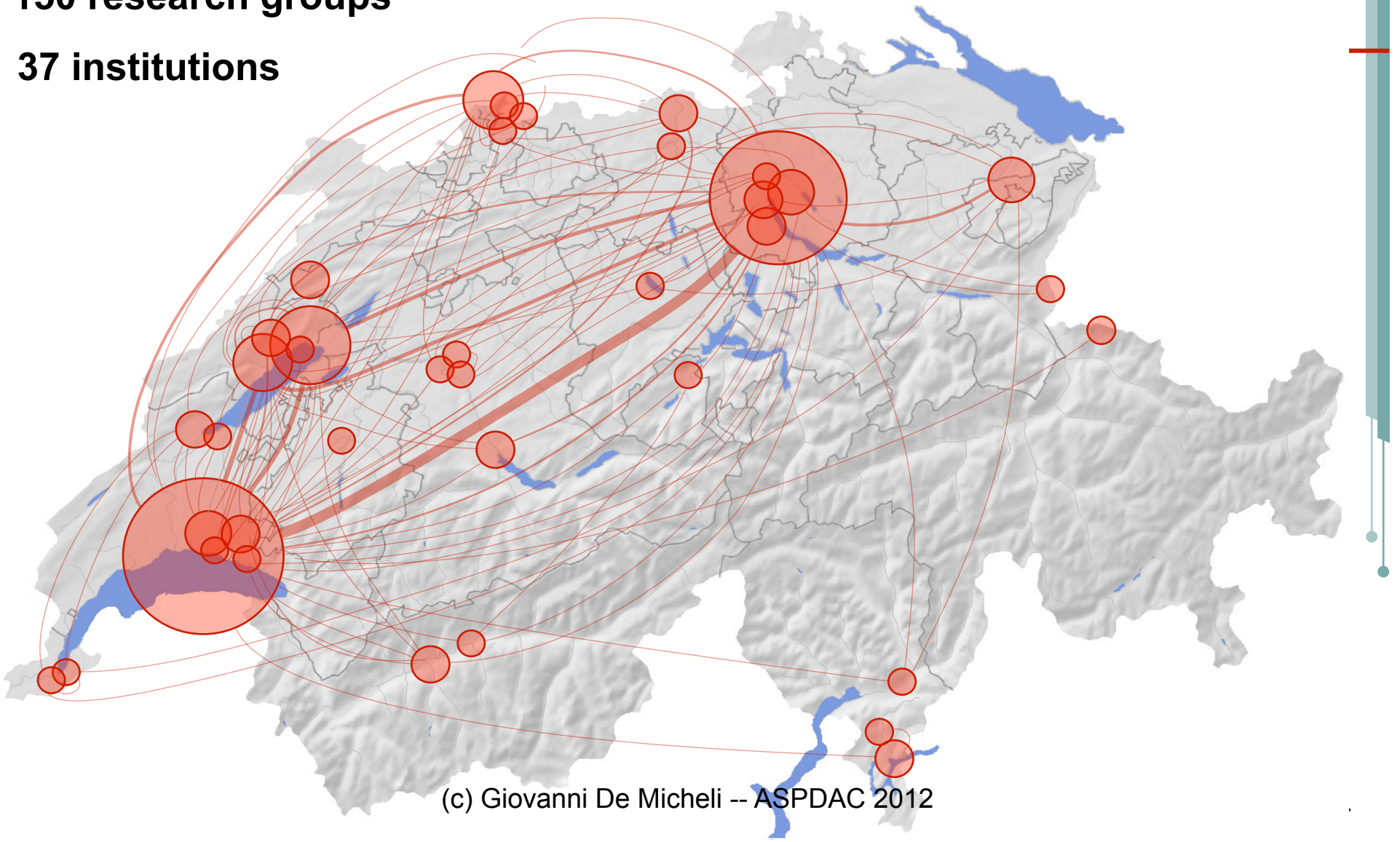
37 institutions



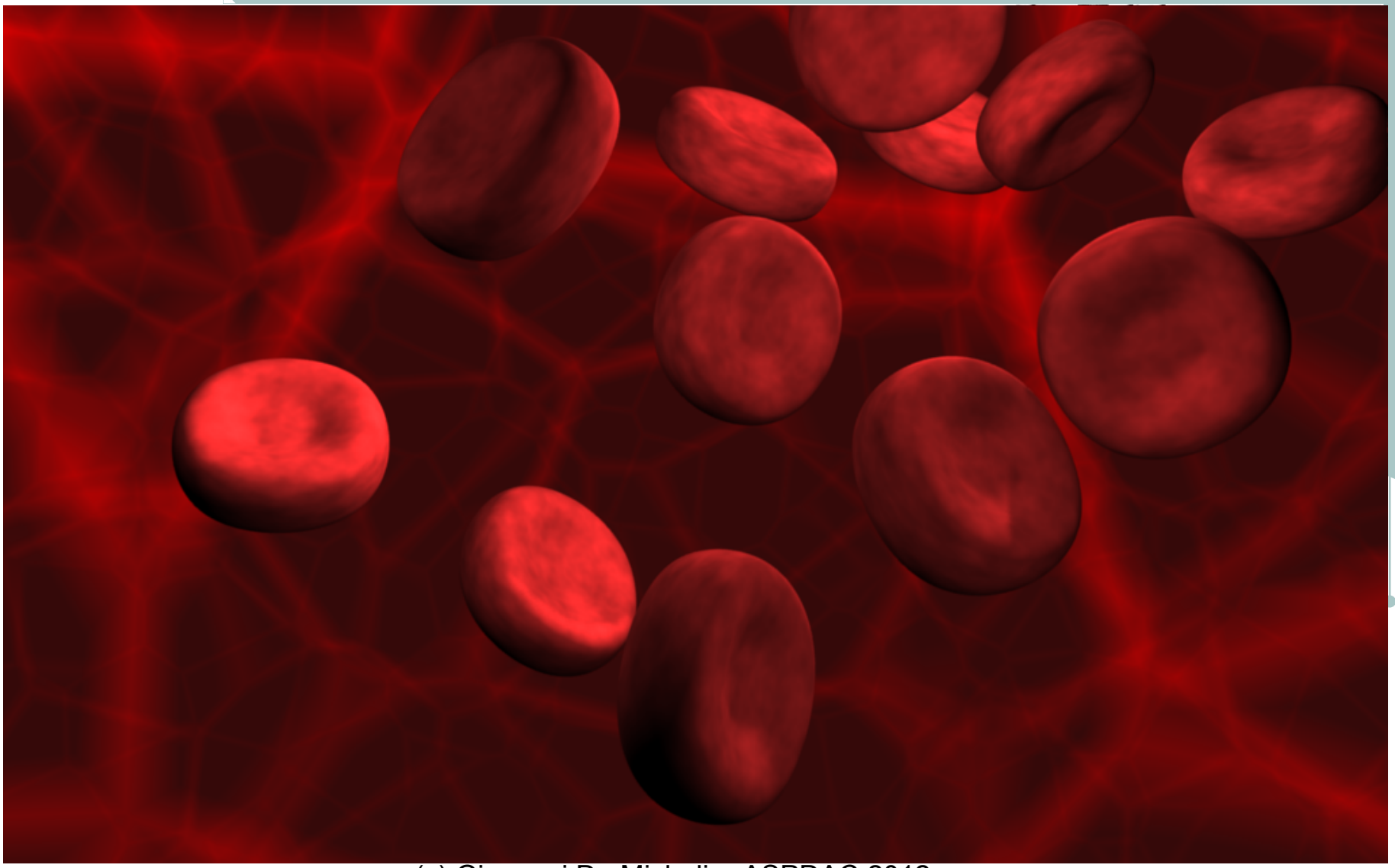
Distribution of research groups

150 research groups

37 institutions



E-Health



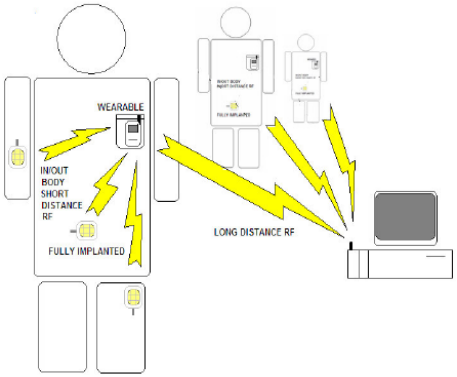
i-IronIC

Implantable/wearable system for online monitoring of human metabolic conditions

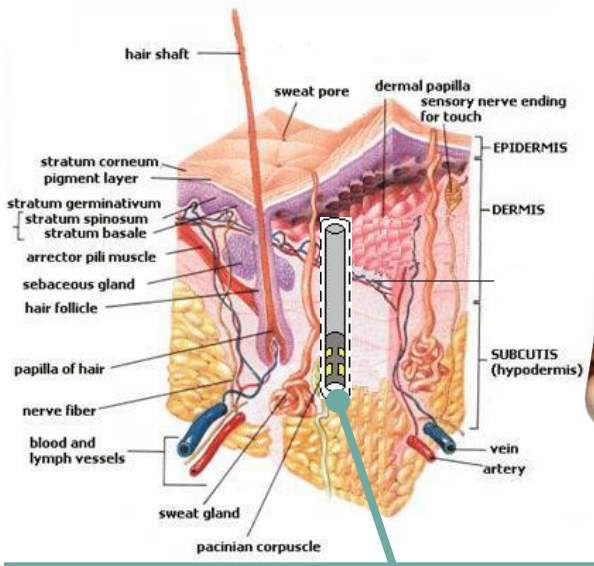
Giovanni De Micheli (EPFL)

Goal: Study an innovative • multi-metabolites • highly integrated • fully implantable • real-time monitoring system for human metabolism

Currently available wearable systems for health monitoring are for glucose



Many different molecules are crucial to monitor:
- lactate
- ATP
- cholesterol



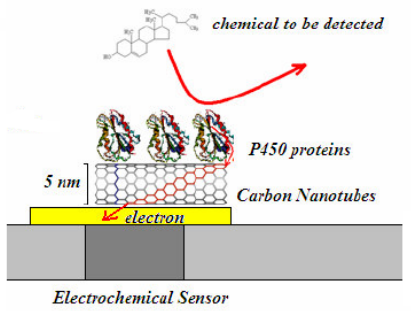
Cylinder: about 2 mm in diameter and below 20 mm in length

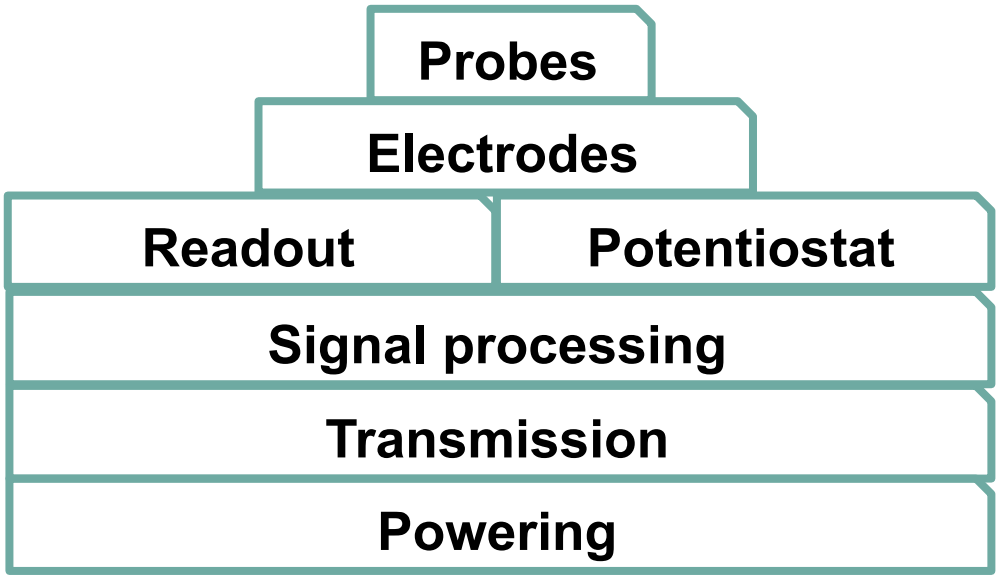
Breakthroughs

- Fully implantable sensor system
- Multi-panel sensors to sense several metabolites (lactate, cholesterol, ATP, etc.) in parallel, in real-time
- New design for fully-implanted, complex and low-power electronics for sensing and with remote powering

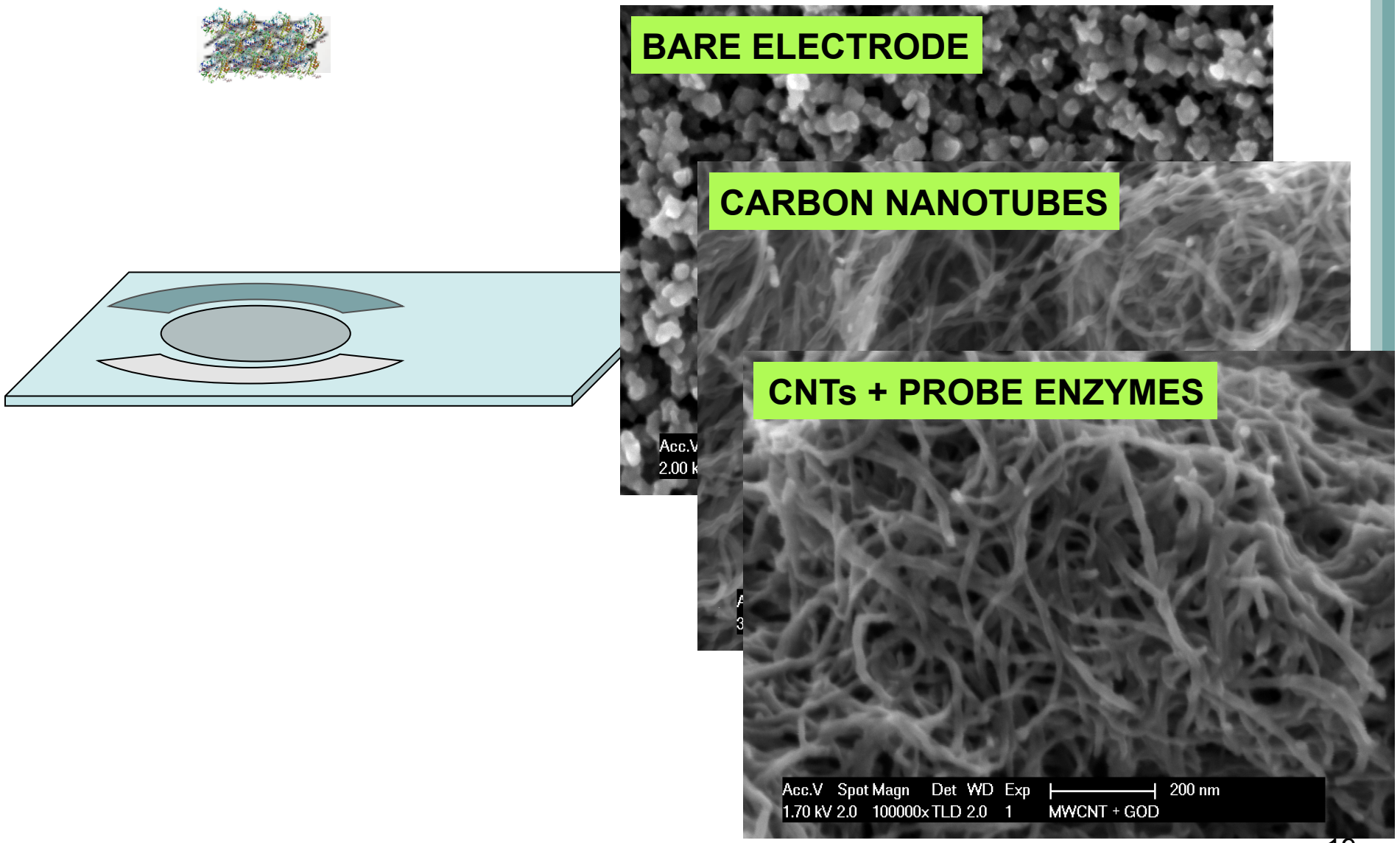
Medical platform design

- Specific components
  - Probes and electrodes
  - Chambers and fluidic circuits
- Electronic components
  - Transconductance amplifier and data conversion
  - Transmission and powering

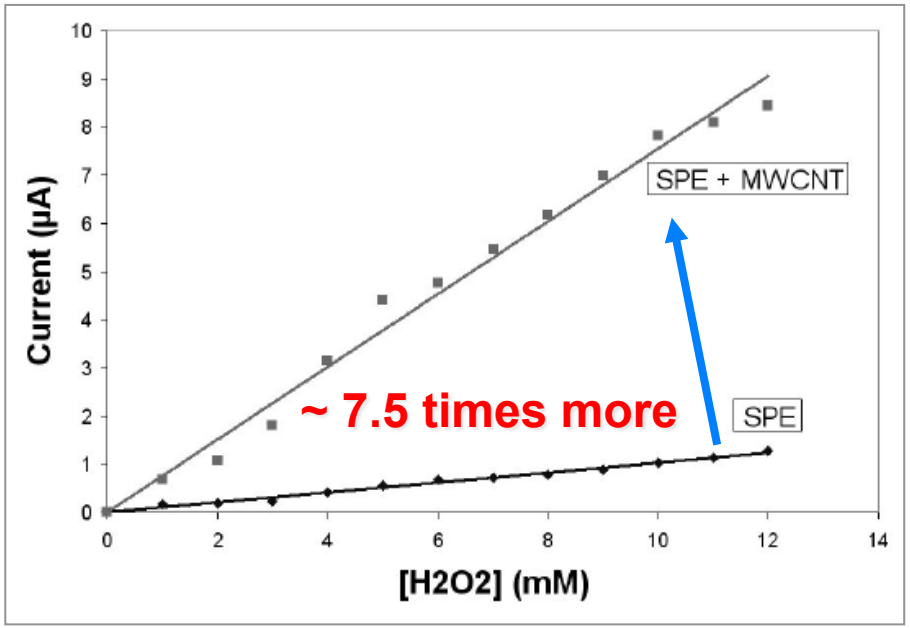




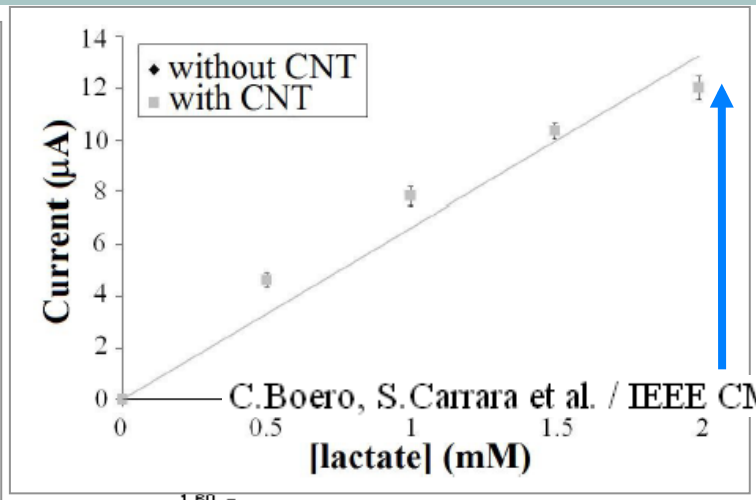
Enhanced nano-bio-sensing

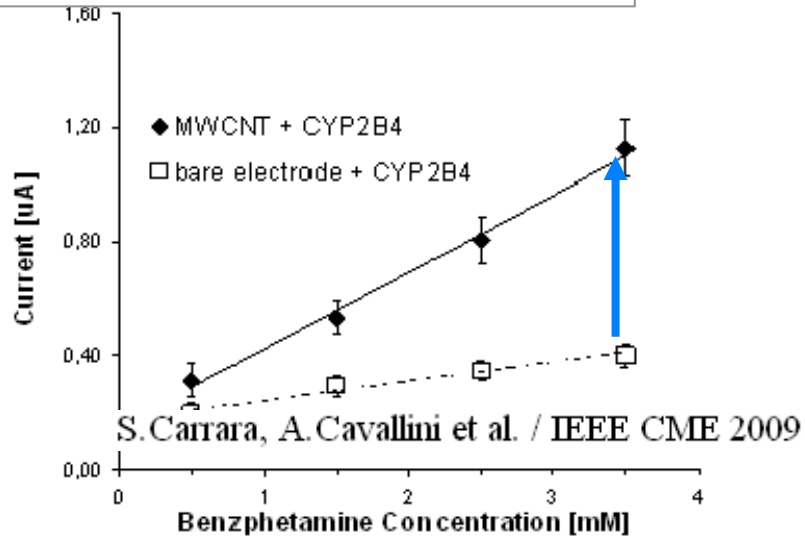


Increased sensitivity



C. Boero, S.Carrara et al., IEEE PRIME, 2009

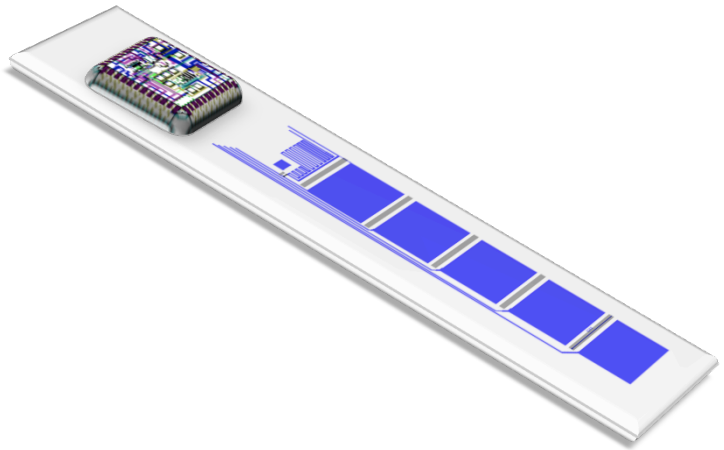


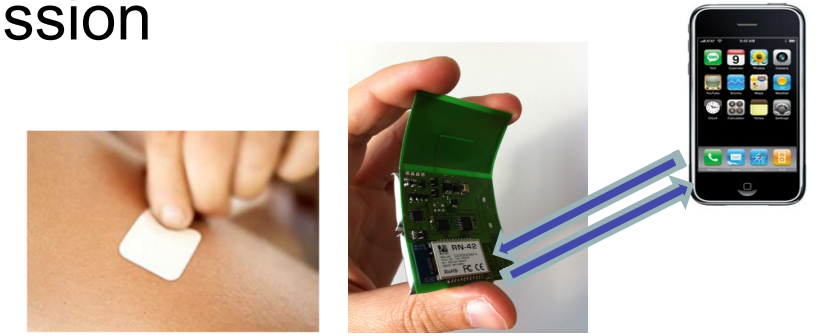


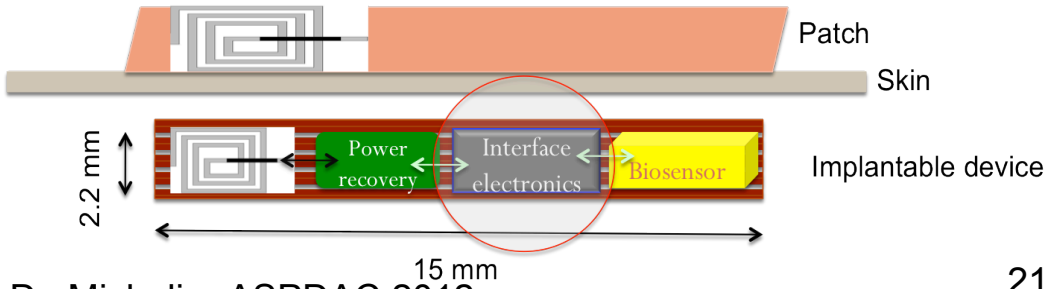
Sensor sensitivity is enhanced by nano-structuring the electrodes

Systems considerations

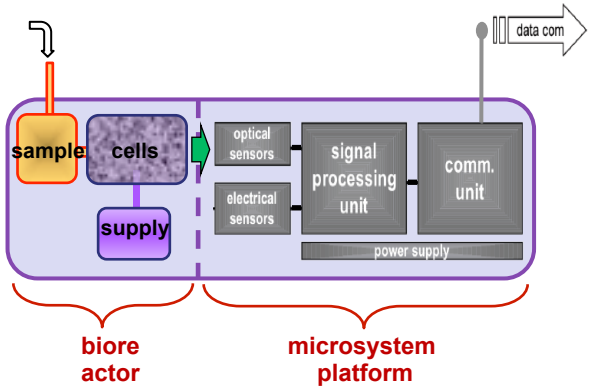
- Multi-panel real-time sensing
  - Use sensor array to do multiple bio-measures, along with temperature and pH sensing
- Low-noise transconductance amplification
  - Low-power operation
- Data and power transmission

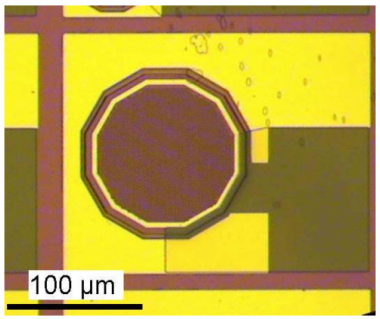


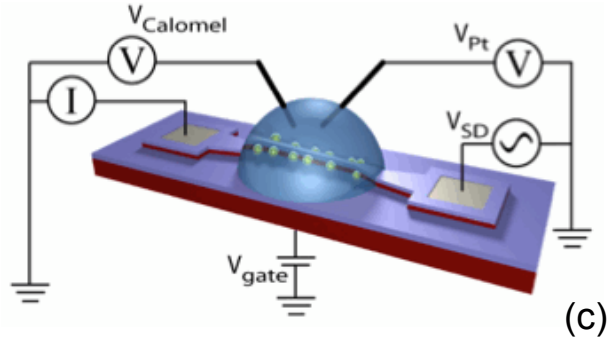




Other sensing platforms







- LiveSense: ***Philippe Renaud (EPFL)***
  - Use living cells, fed by supply, to sense
  - Optical and electrical monitoring
  - Target: toxic compounds in water
- IRSense: ***Jerome Faist (ETHZ)***
  - Use near-infrared absorbance measures
  - Target: organic compounds in fluids
- NanowireSensor: ***C. Shönenberger (U. Basel)***
  - ISFETs based on silicon Nanowires
  - Non-labeled sensing

TecInTex

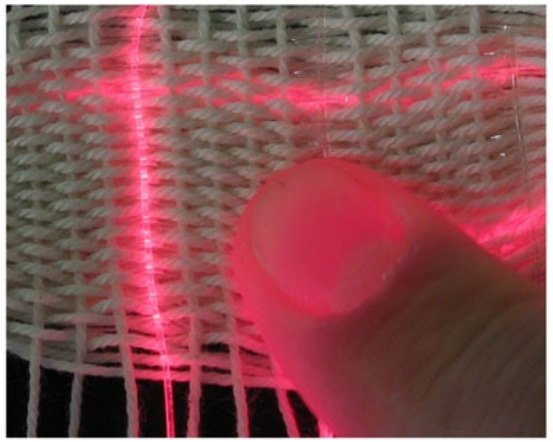
Technology integration into textiles: empowering health

Gerhard Tröster (ETHZ)

Sensing capabilities close to the human body ➡ monitor activity, motion, health…

Incorporate built-in technological elements in our everyday textiles & clothes

Existing E-textiles: low processability, wearing comfort, washability…



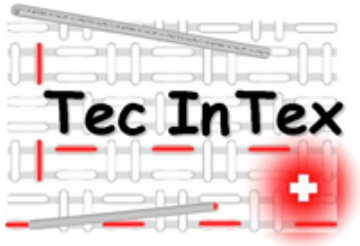
➡
- **design & manufacture truly wearable functional clothes**
- **electronic fibers**
- **optical fibers**
- **transducer between optical & electrical signals**

Near infrared spectroscopy sensing

Peripheral vascular diseases: 30% of adults

Early detection possible (near IR spectroscopy), but conventional sensors are cumbersome

Light wearable system in sock to monitor tissue oxygenation continuously & non-invasively



Intelligent underwear for paraplegic people

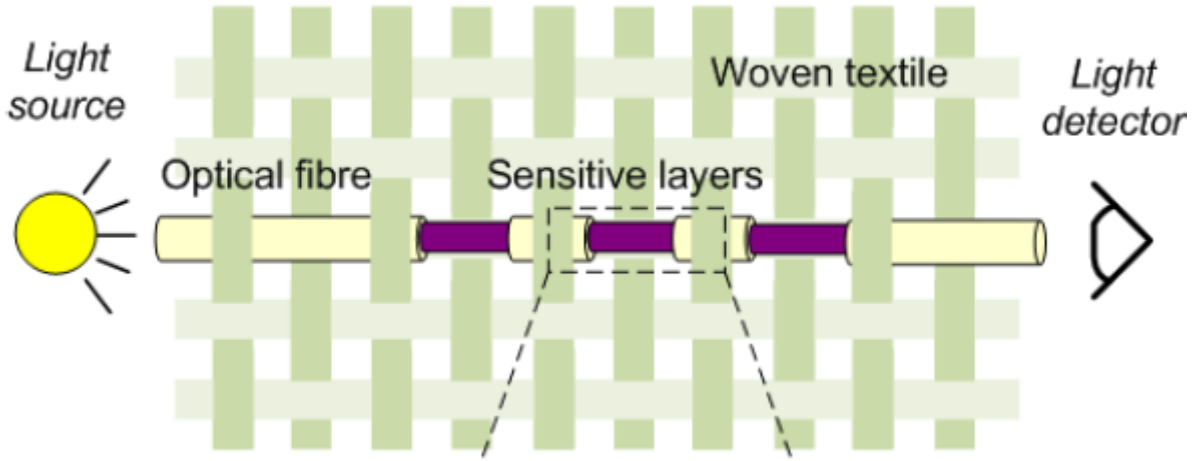
Pressure ulcers are serious problems for paraplegic and bed ridden patients

➡ **Build a comfortable device to detect the risk for pressure ulcers in order to enable preventive measures**

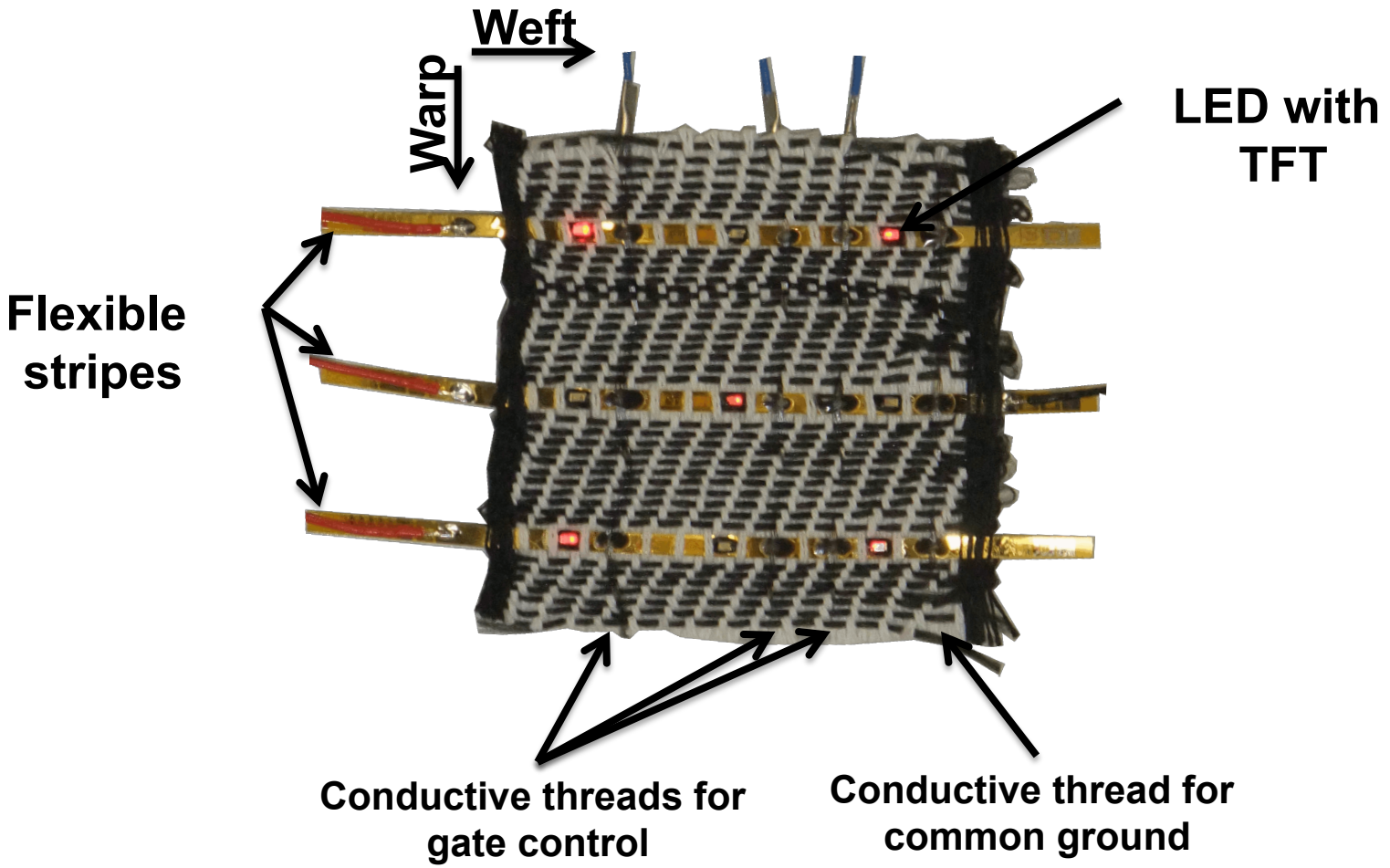
ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich · EMPA · csem · UniversitätsSpital Zürich · Swiss Paraplegic Centre

Weaved optical sensor design

- Modify optical fibers with sensitive porous layer
  - Specific to biomarkers
  - pH sensors (variation in color)
- Detection based on variation of light absorbance
- Fibers, detectors and light sources into fabric



Weaved electrical fabric



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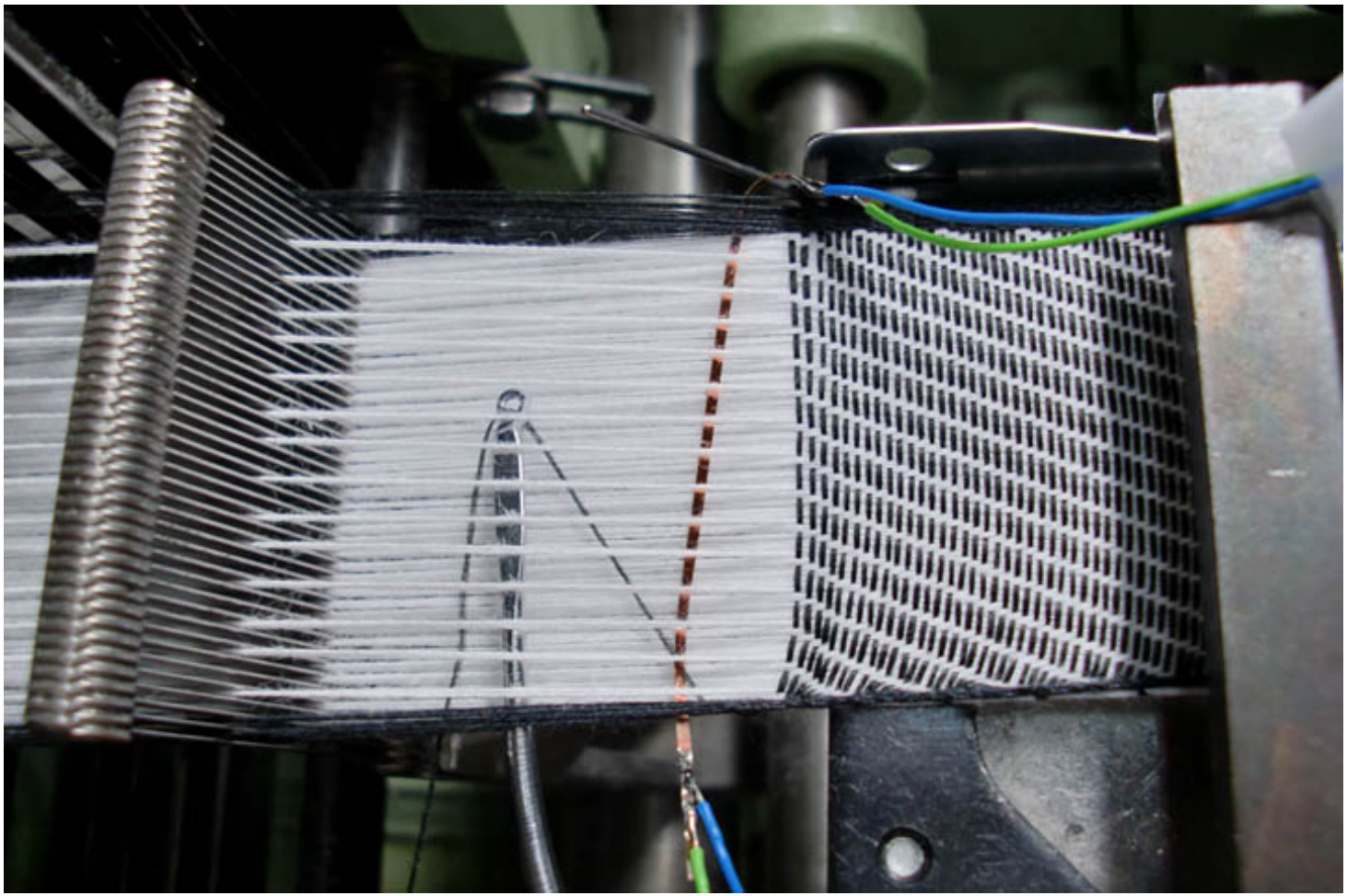
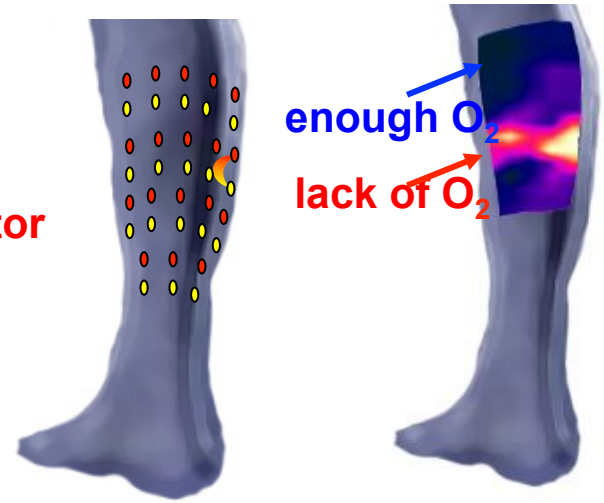
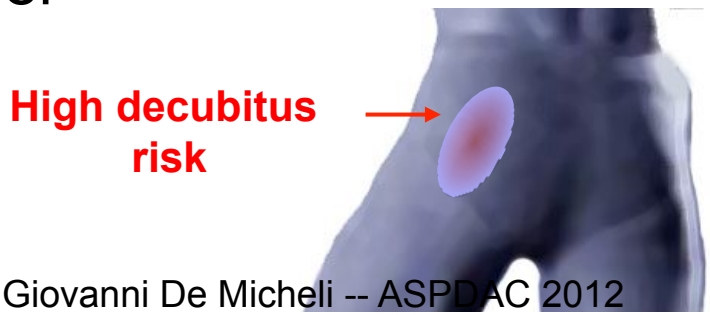


Applications and demonstrators

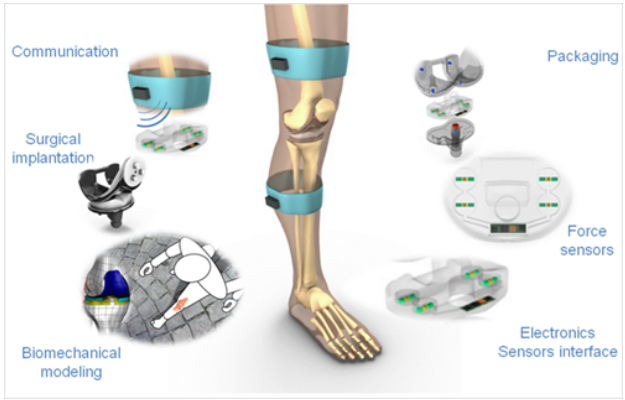
- NIRS (Near Infrared Spectroscopy) in socks
  - Early detection and treatment of peripheral vascular disease (PVD)



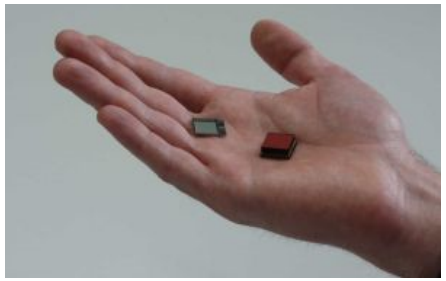
- Intelligent underwear for paraplegic people to prevent and to treat ulcer



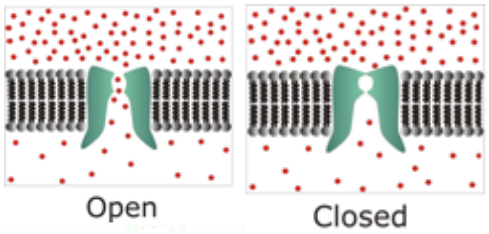
Other medical projects



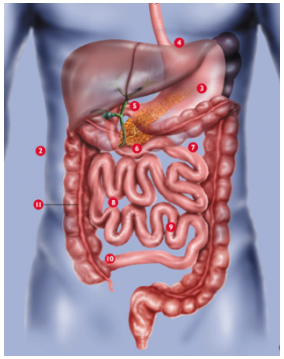
Monitor knee implants



Mini x-ray sources



Intelligent drug delivery



Organ emulation

E-Environment

Environment systems

Large-scale distribution of auto-configurable networks of sensor nodes

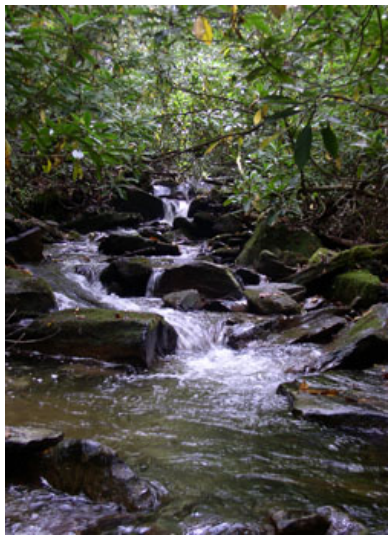
to sense – network – inform – actuate – interact with the physical environment, the devices and humans

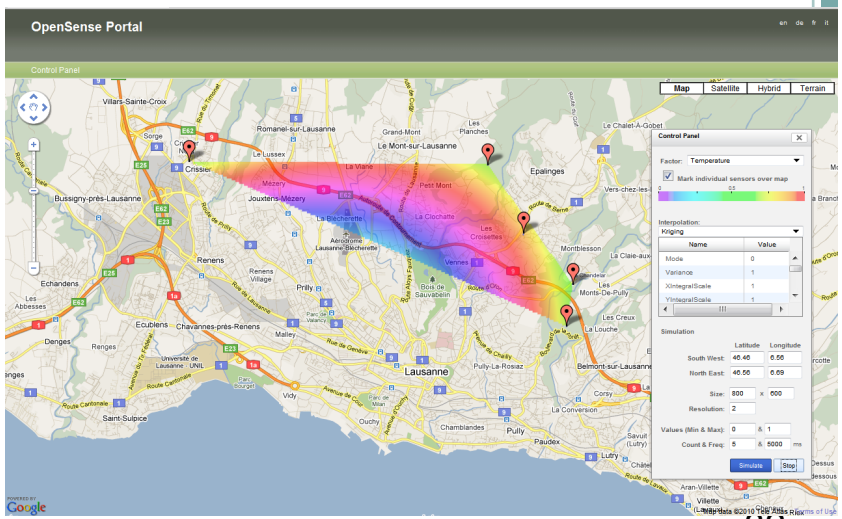
Next generation information technology, with devices that are…

- highly distributed
- networked
- heterogeneous
- largely self-organizing
- embedded into the environment

Application areas

- Environmental monitoring
- Smart buildings & workplaces
- Smart transportation systems
- Virtual-world applications





OpenSense

Open sensor networks for air quality monitoring

Karl Aberer (EPFL)

Community driven, large-scale air pollution measurement in urban environments

- Important problem: **air pollution**
- **Few monitoring stations** measure pollutants

- Important technical opportunities & challenges
  - Massive measurements that exploit:
    - wireless sensor networks
    - mobile stations
    - community involvement
  - More data, more noise… also more redundancy
    - Can we produce better quality data?

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

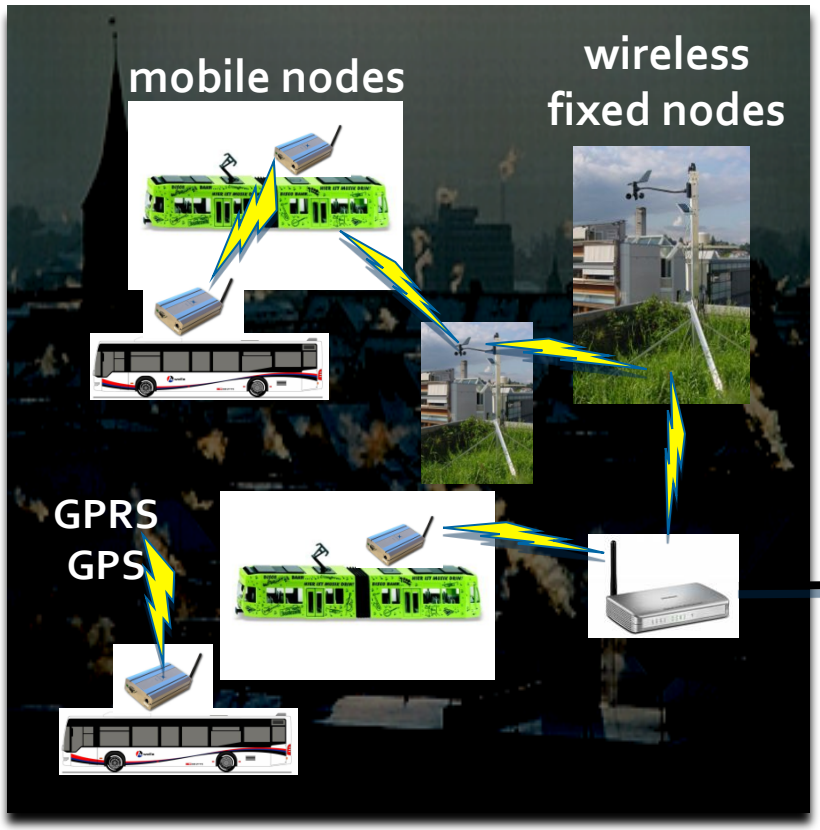
OpenSense: challenges

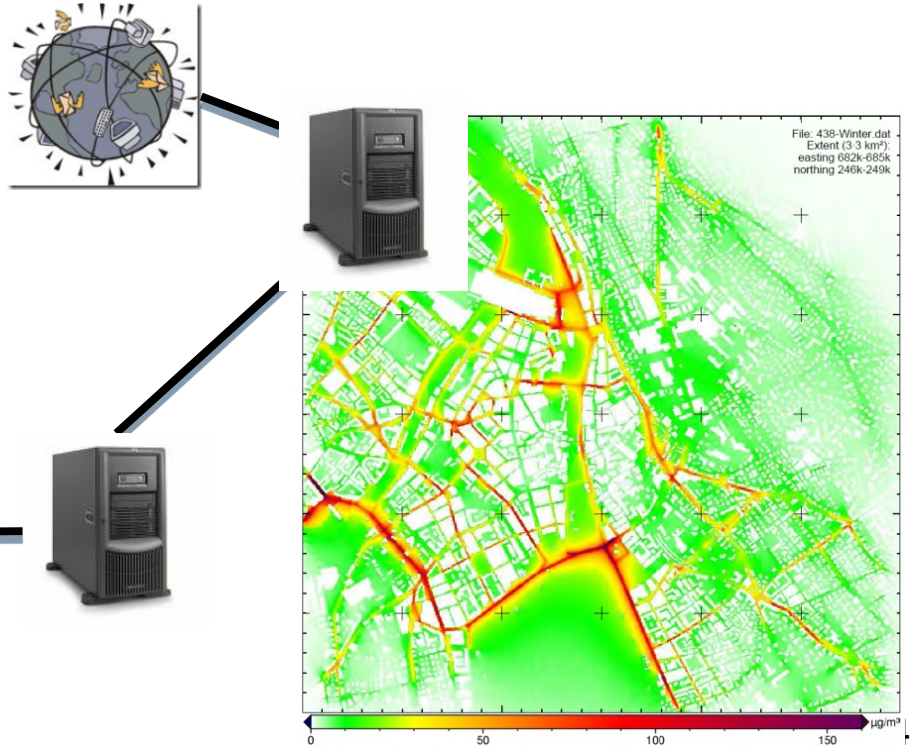
NANO

SENSING SYSTEM
From many wireless, mobile, heterogeneous, unreliable raw measurements …

INFORMATION SYSTEM
… to reliable, understandable and Web-accessible real-time information

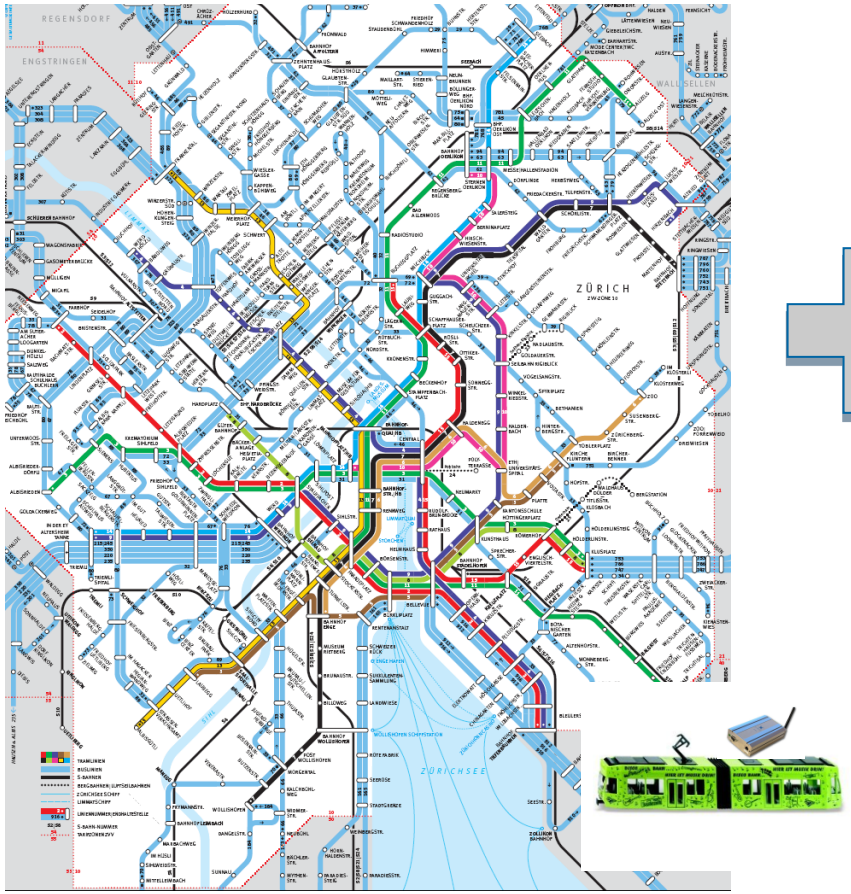
TERA





Sensing infrastructure

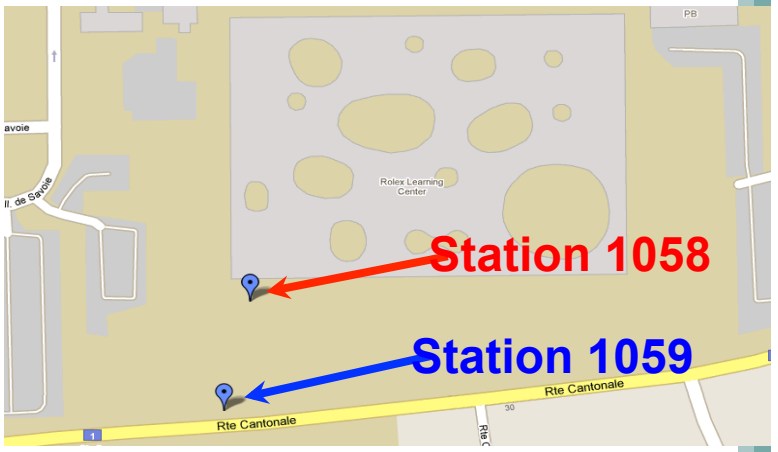
Mobile sensor nodes on public transportation and private mobile devices



Wireless sensing and communication infrastructure

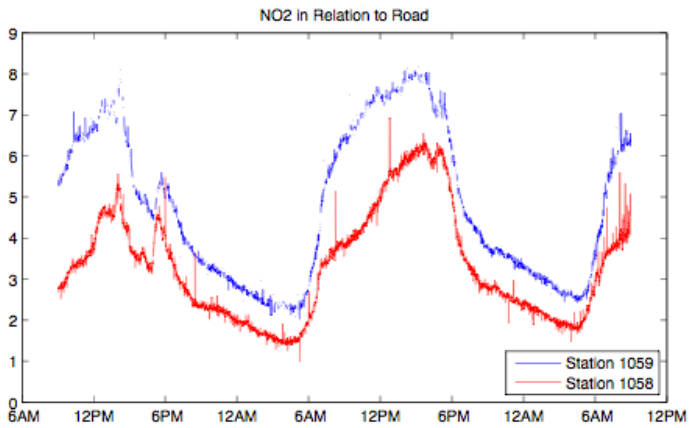
Lausanne: stationary infrastructure

- 2 prototype stationary stations
  - NO2 (2 sensors), CO (2 sensors), Humidity, Temperature
  - Solar panel powered
- 1 station next to Nabel
- 12 stations deployed in 2012



EPFL campus

Lausanne Nabel station

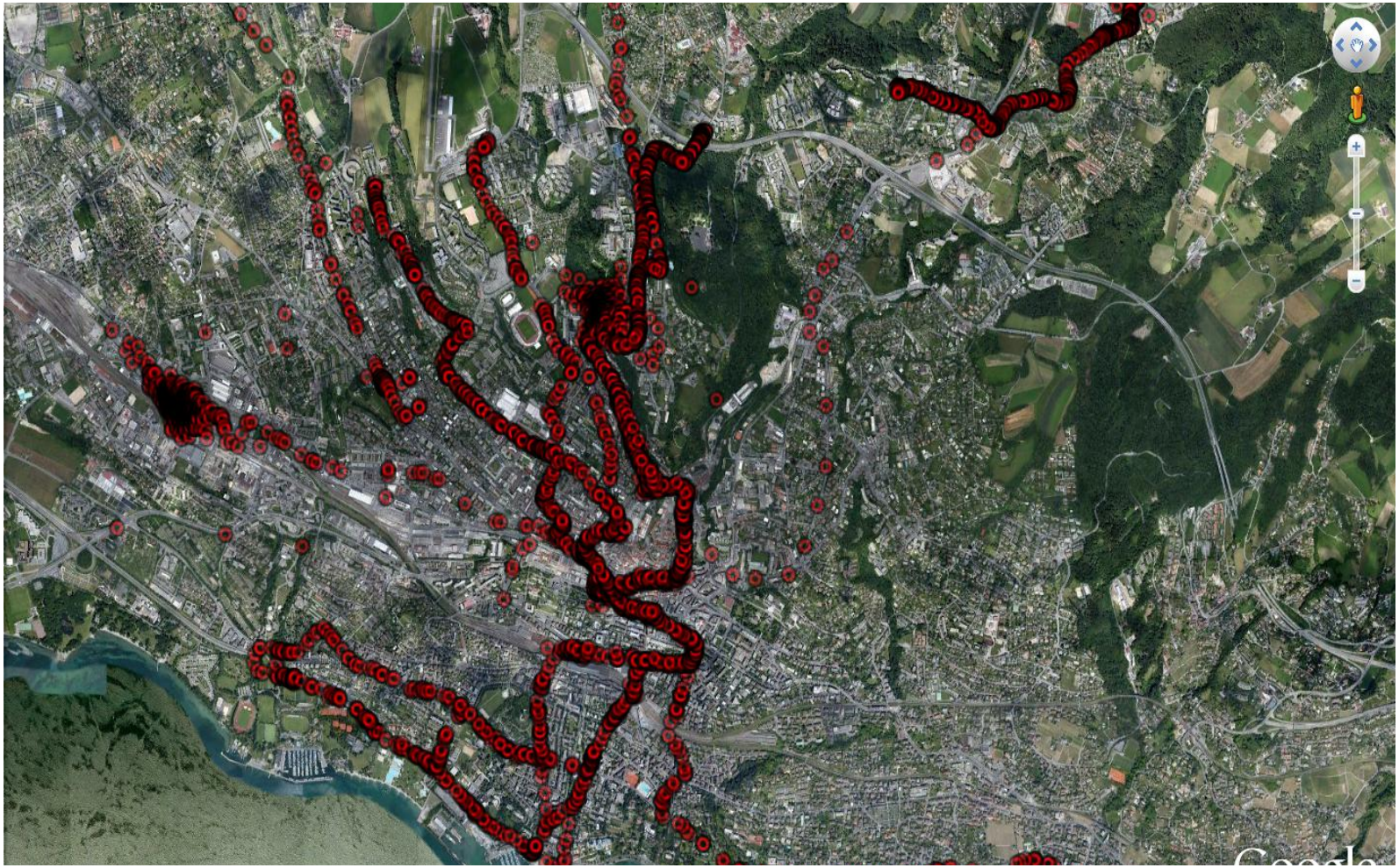


10 m distance result in significant difference

Lausanne: mobile infrastructure

- 1 prototype station mounted on bus
  - NO2, CO (2 sensors), CO2, Humidity, Temperature
  - Positioning module
  - Powered by bus
- 8 mobile stations being deployed

Lausanne coverage

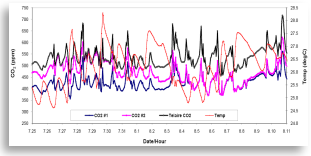


OpenSense: scientific challenge

Is massive sensing with large numbers of heterogeneous and mobile sensors technically feasible and practically useful?

Use of correlations

Need to compress, clean & interpret the huge amount of data generated



➡ Identify and exploit spatial & temporal correlations in sensor data

Mobile sensors

- Intermittent communication
- Sensor position keeps changing
- Need to minimize measurements to reduce power consumption

Community sensing

High public interest

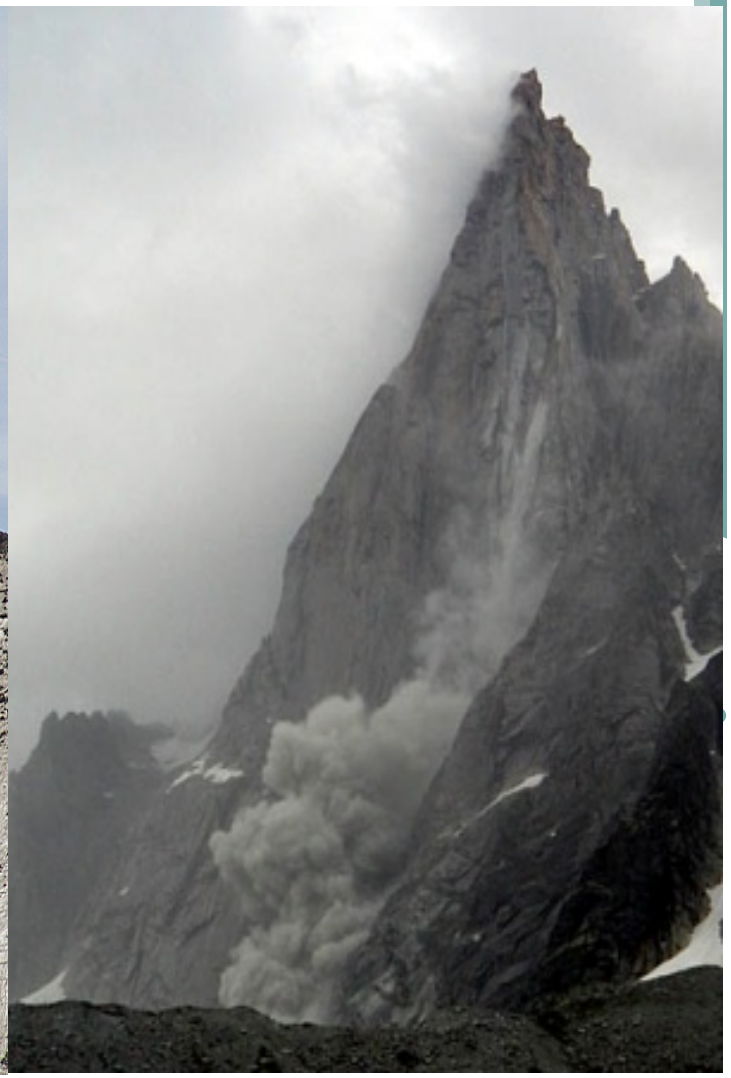
➡ Make gathered data available to a large community

With producers of data: reliability and trustworthiness of the information

X-Sense

Monitoring alpine mass movements at multiple scales

Lothar Thiele (ETHZ)



ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Universität Zürich

GAMMA REMOTE SENSING

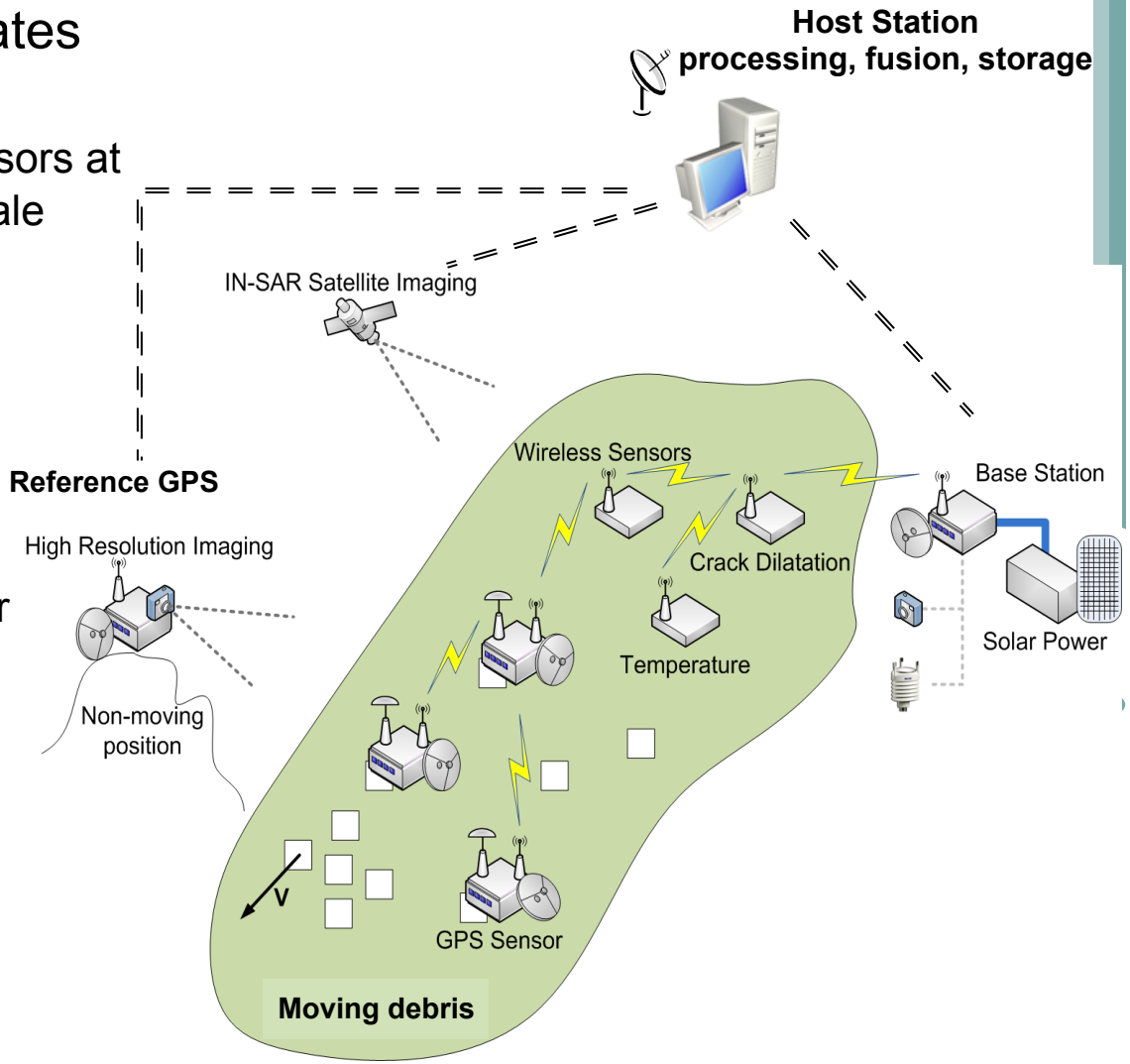
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

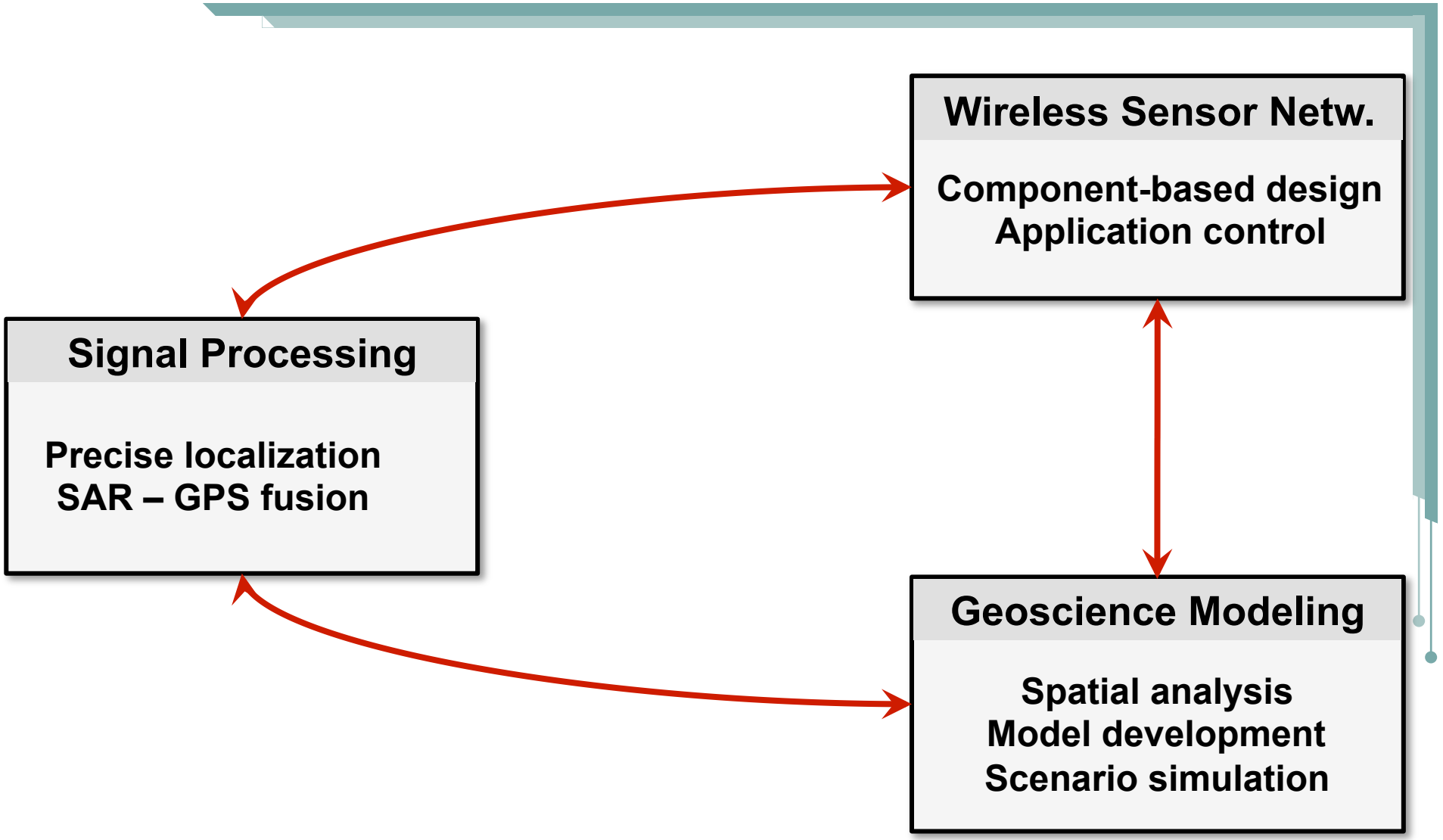
Federal Office for the Environment FOEN

X-Sense hypothesis

- Anticipation environmental states and risk improved by
  - A systematic combination of sensors at different temporal and spatial scale
- Wireless Sensor Networks
  - Allows us to quantify mountain cryosphere phenomena and their response to climate change
  - Can be used for safety critical applications in a hostile environment

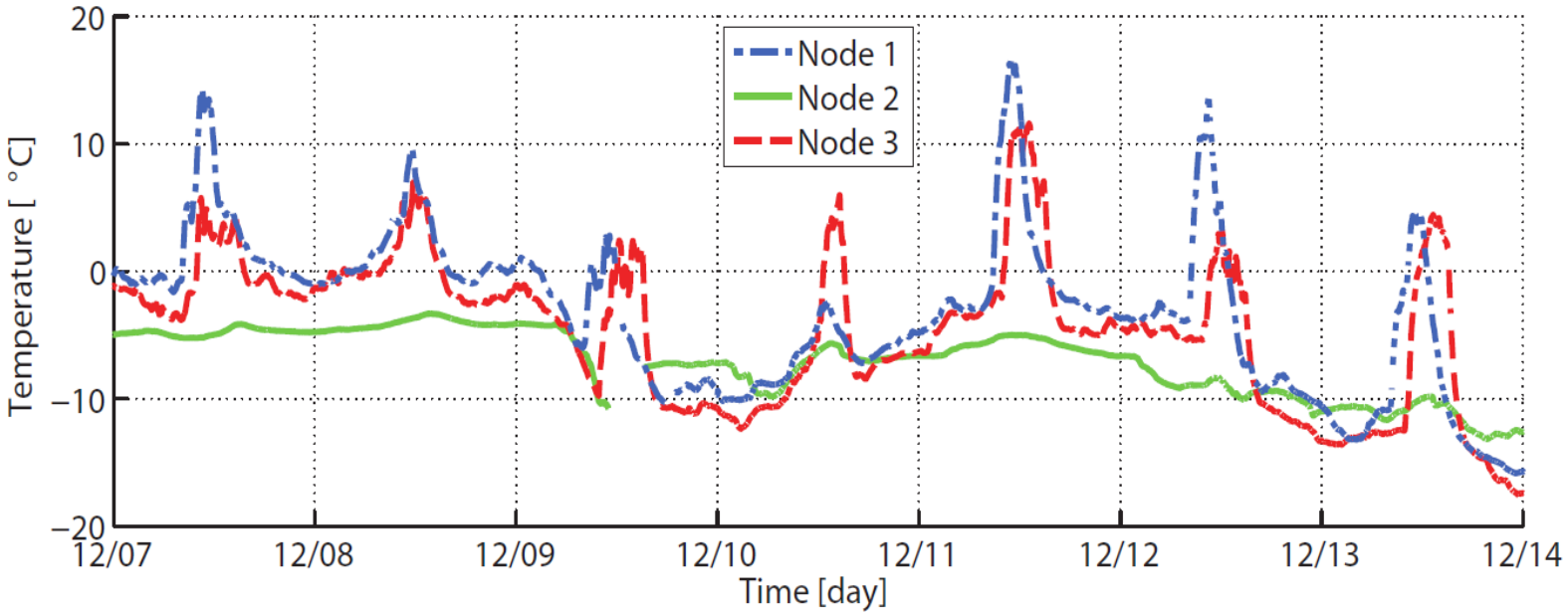


X-Sense task structure

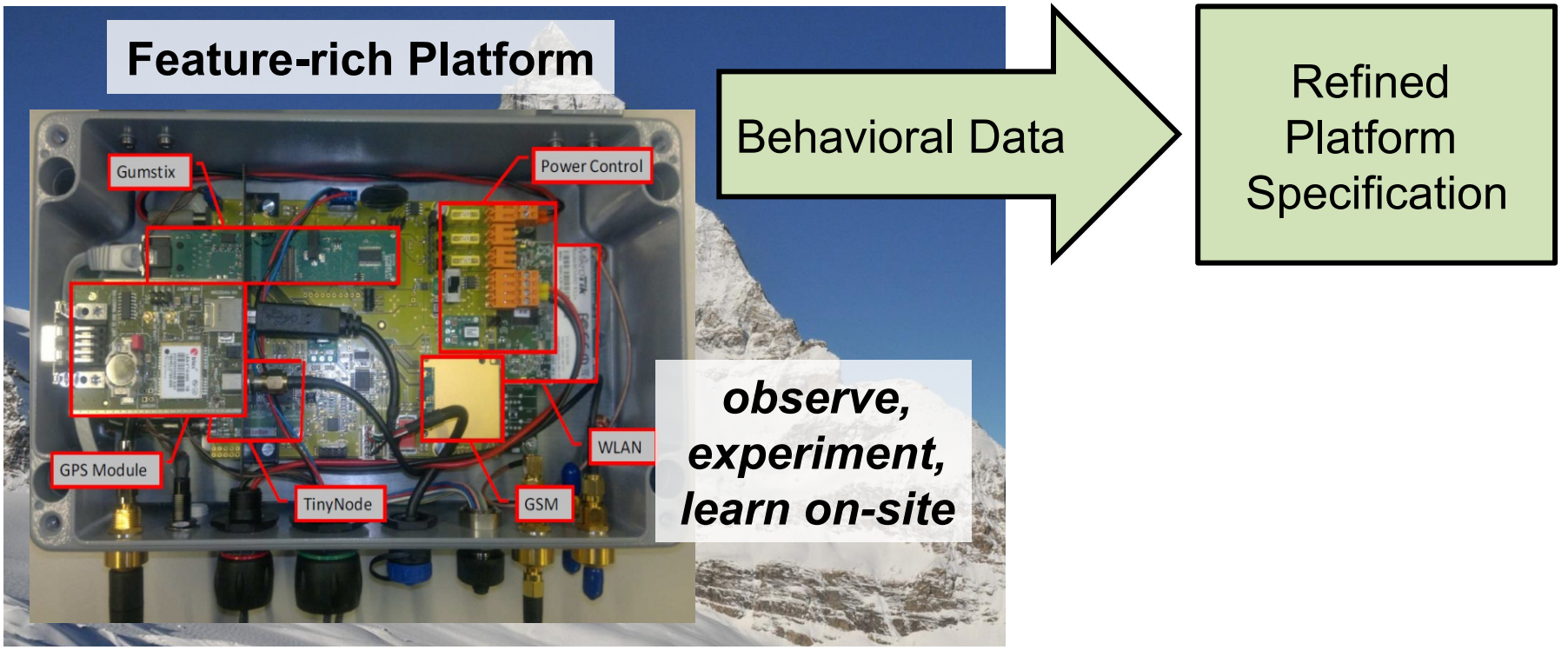


Challenge: the physical environment

- Lightning, avalanches, rime, prolonged snow/ice cover, rockfall
- Strong daily variation of temperature
  - −30 to +40°C
  - ΔT ≦ 20°C/hour



In situ design and test

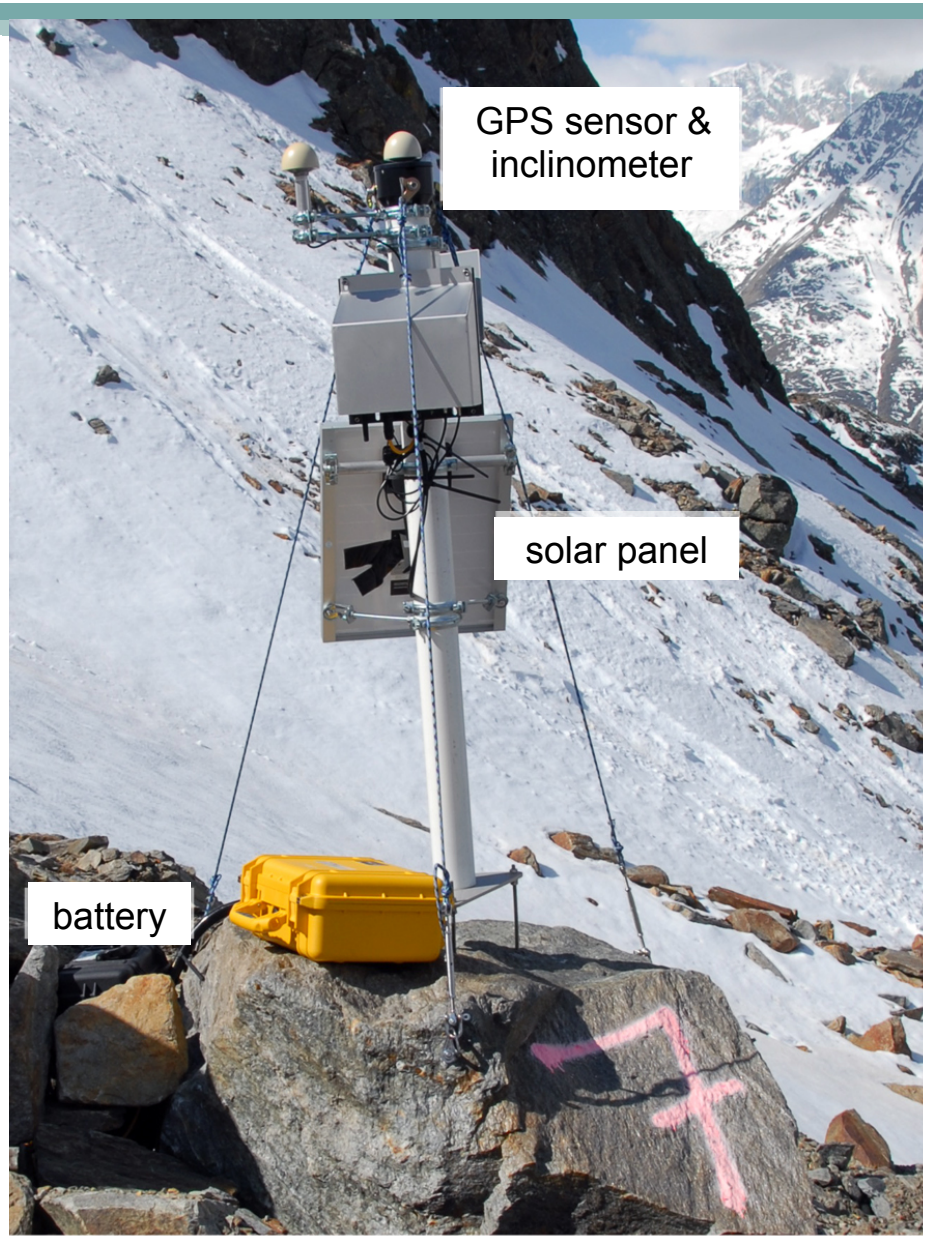


- Flexible in-situ exploration (testbed ≠ real system)
- Real sensor data, real environment
- Integration with live data management (system of systems)

GPS measurement devices

Low-cost GPS Devices

- Dual strategy: logging units & wireless sensors
- High temporal resolution
- Accurate displacement-rate of a boulder (mm-cm accuracy for daily position)

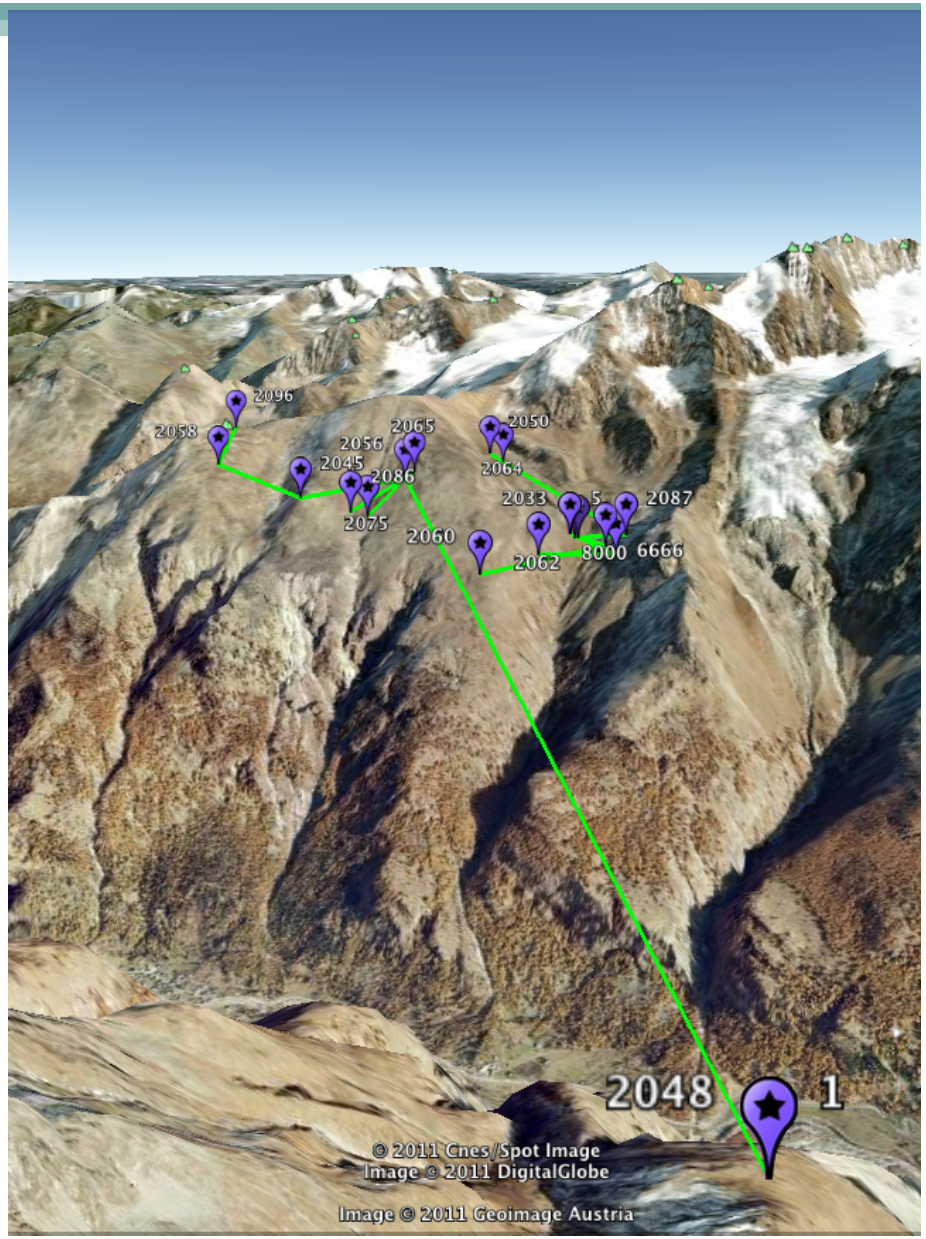


GPS deployment: Matter valley

Field Site Inventory

- 9 GPS on composite landslides
- 8 GPS on rock glaciers
- 4 GPS as position reference stations
- 5 simple temperature loggers per GPS station
- 2 Meteo stations
- 1 camera

Installation started August 2010,
with full operability in August 2011

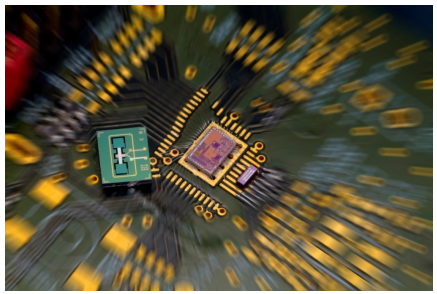


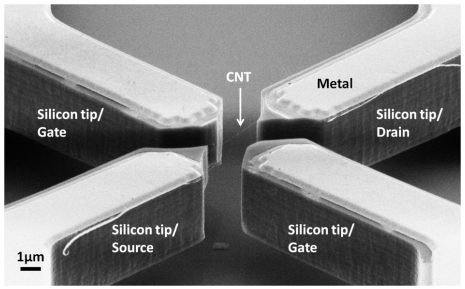
X-sense: scientific challenges

- Design, deploy, test sensor nodes
  - Rugged electronics
  - Highly-reliable units
- Gather, fuse data from various sources
  - Algorithms and software for data processing
- Map data onto to geological model
  - Correlate physical measurements
- Extract potential alarming situation

Enabling technologies and platforms

- *Enabling technologies* as common research areas to support health and environment application
  - Micro/nano-electronics
  - Sensors
  - MEMS/NEMS
  - Information and communication systems
- *Design platforms*
  - Low power sensing, processing and communication
  - 3-Dimensional integration and packaging
  - Body-area and *ad hoc* networks





Conclusions

- Nano-Tera.ch exploits **new technologies** and devices:
  - *Silicon nanowire* and *carbon nanotube* devices
  - *Integrated electronics* and *sensors*
- With the objective of building **heterogeneous** systems:
  - Monitor health in patients, disabled and elderly
  - Monitor the environment for pollution and to prevent disasters
- And with the final goal of increasing the **security** of individuals and communities
  - Key contribution of engineering to coping with complex societal and economic problems
  - Requiring large and collaborative intellectual effort

Thank you